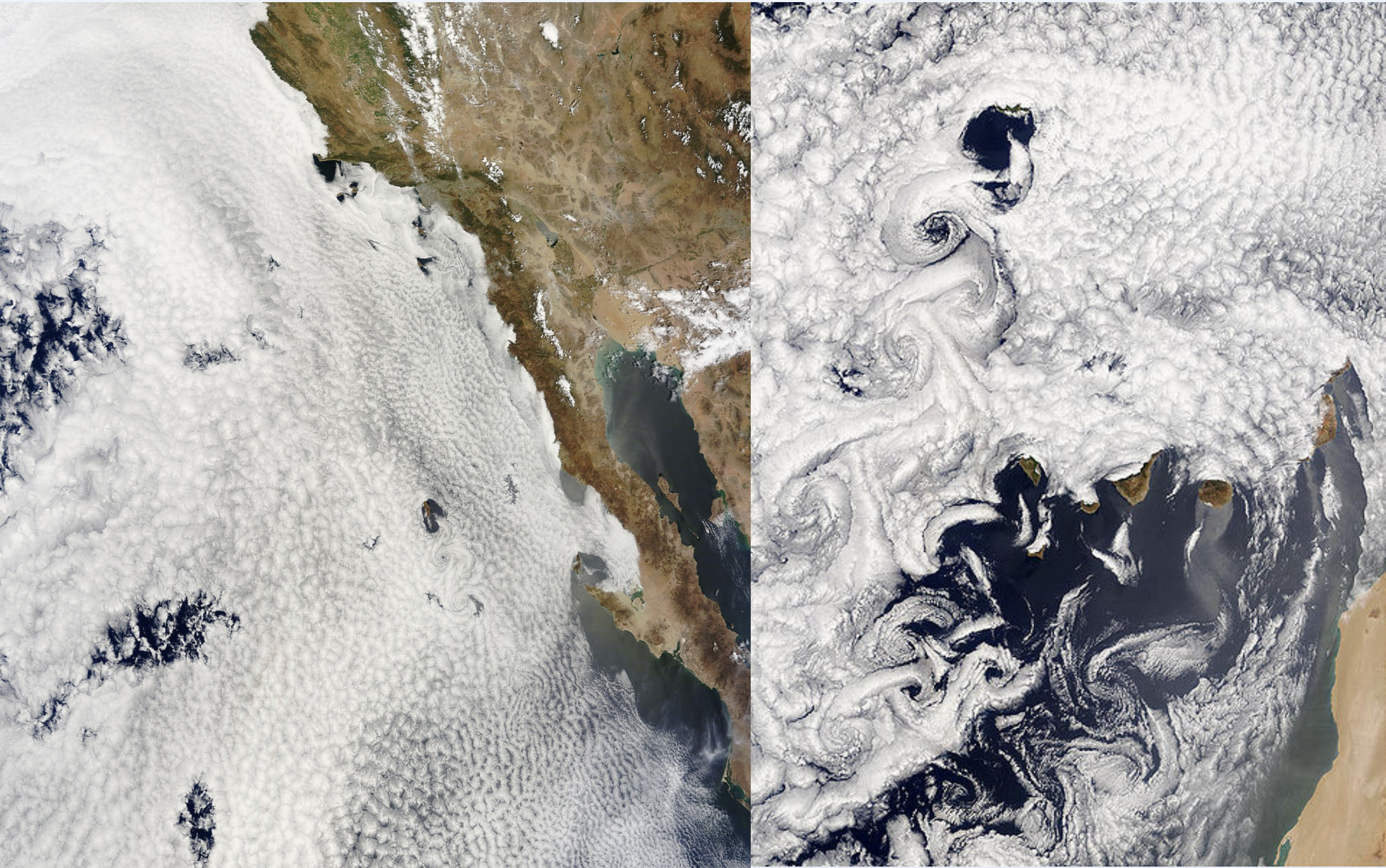
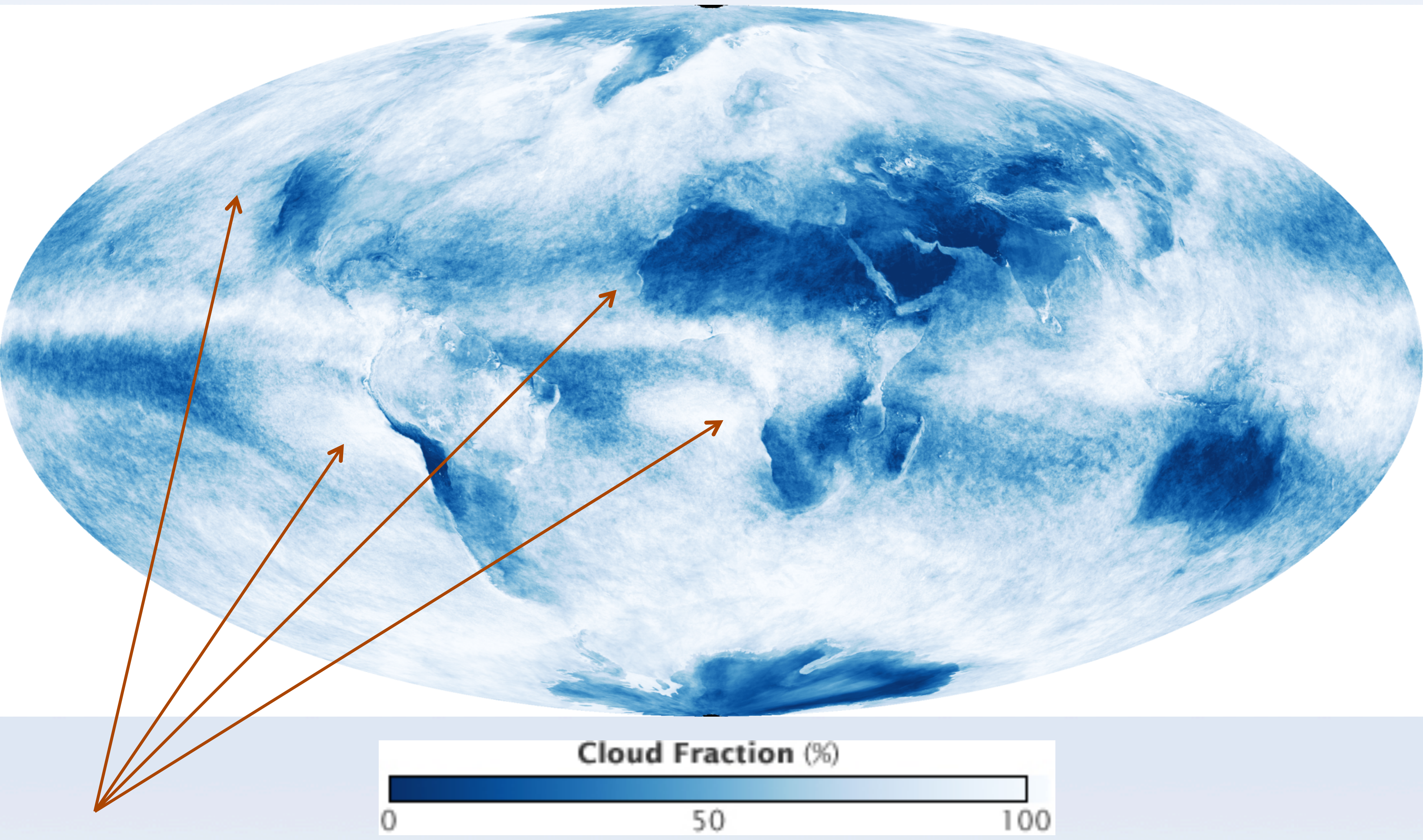
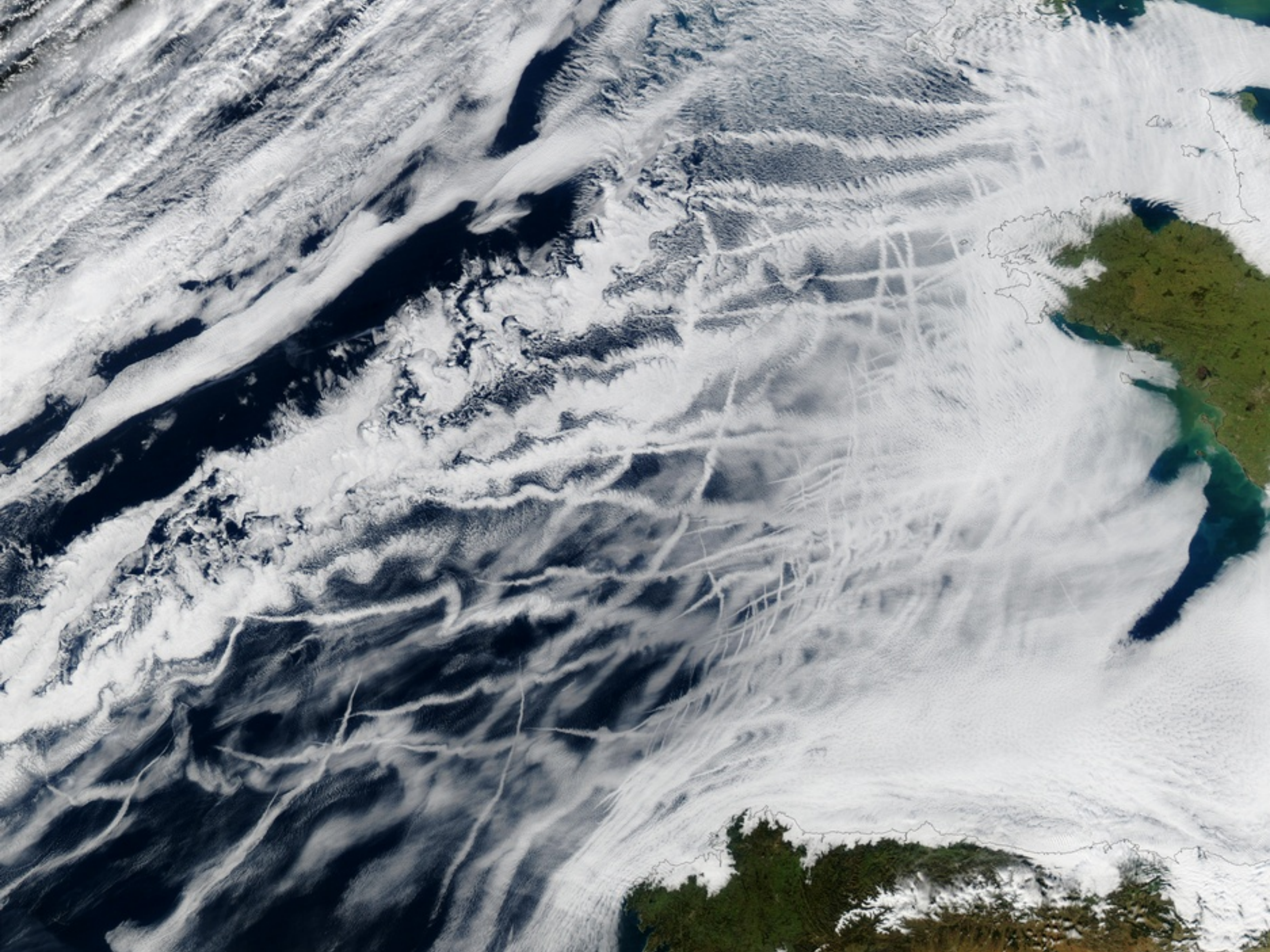
On Clouds Rabbits and Foxes

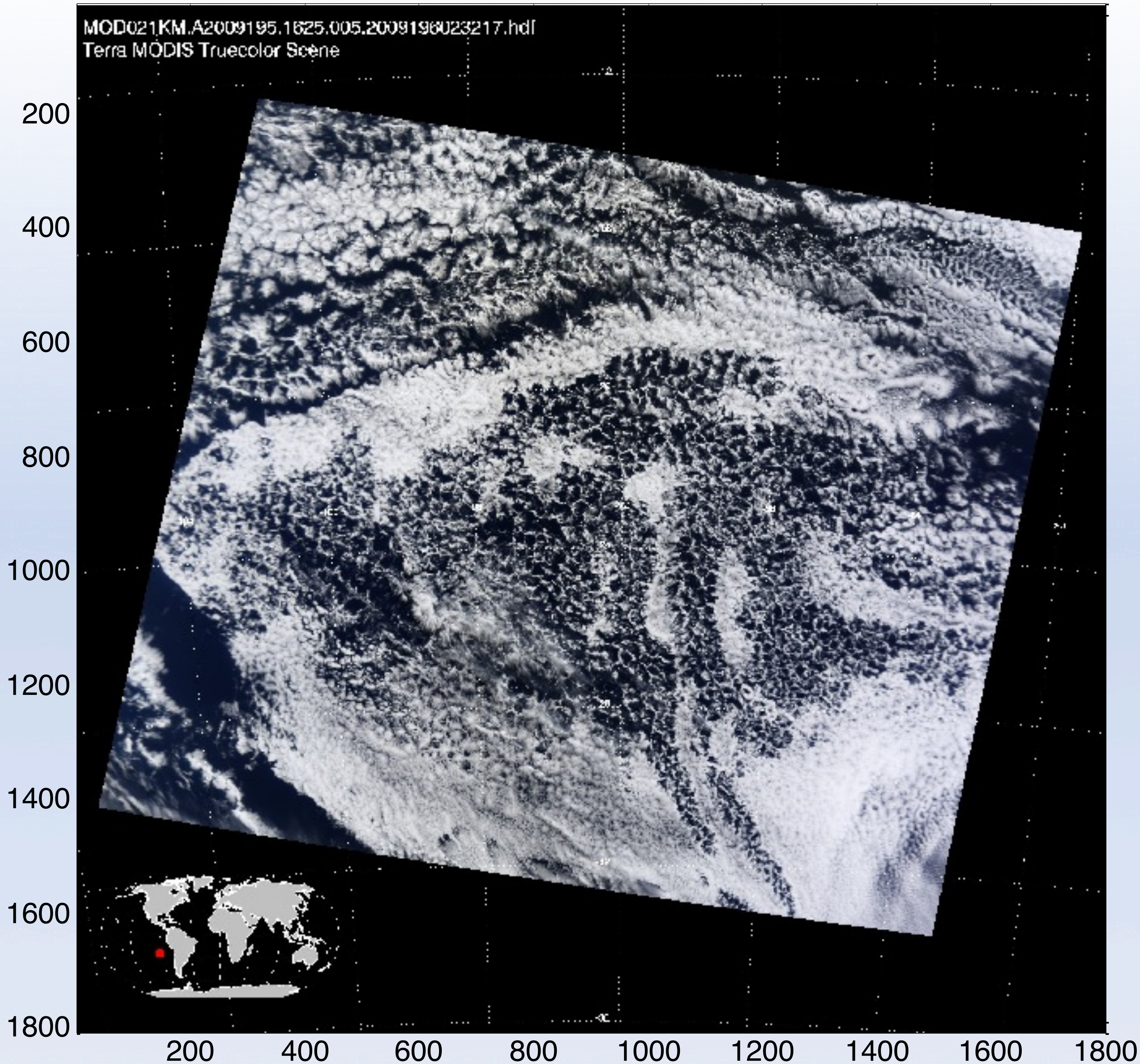
Graham Feingold – NOAA Boulder CO

Marine Stratocumulus - the global reflectors




Cloud Fraction (%)
0
50
100




MOD021KM.A2009195.1625.005.2009196023217.hdf
Terra MODIS Truecolor Scene
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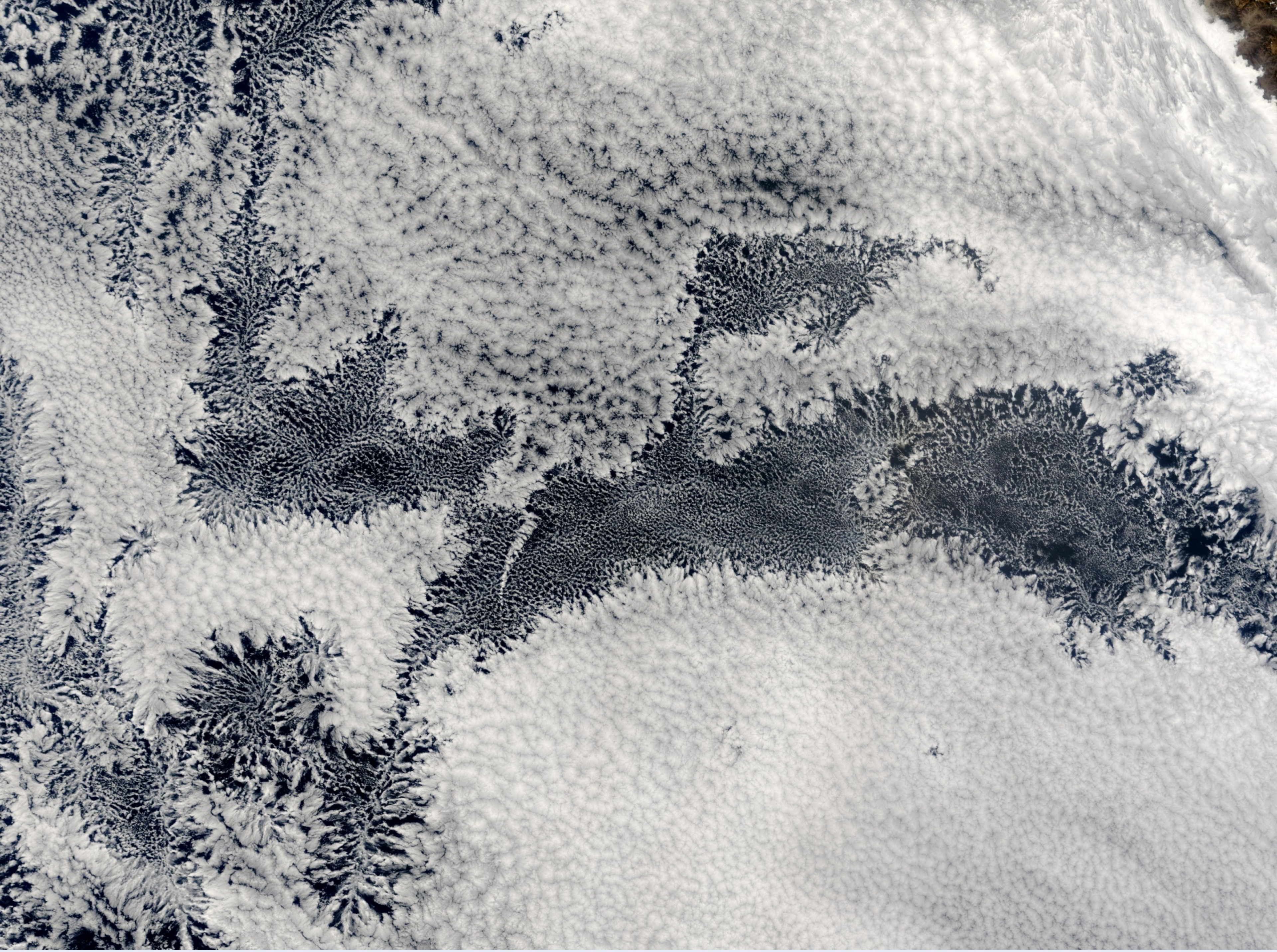
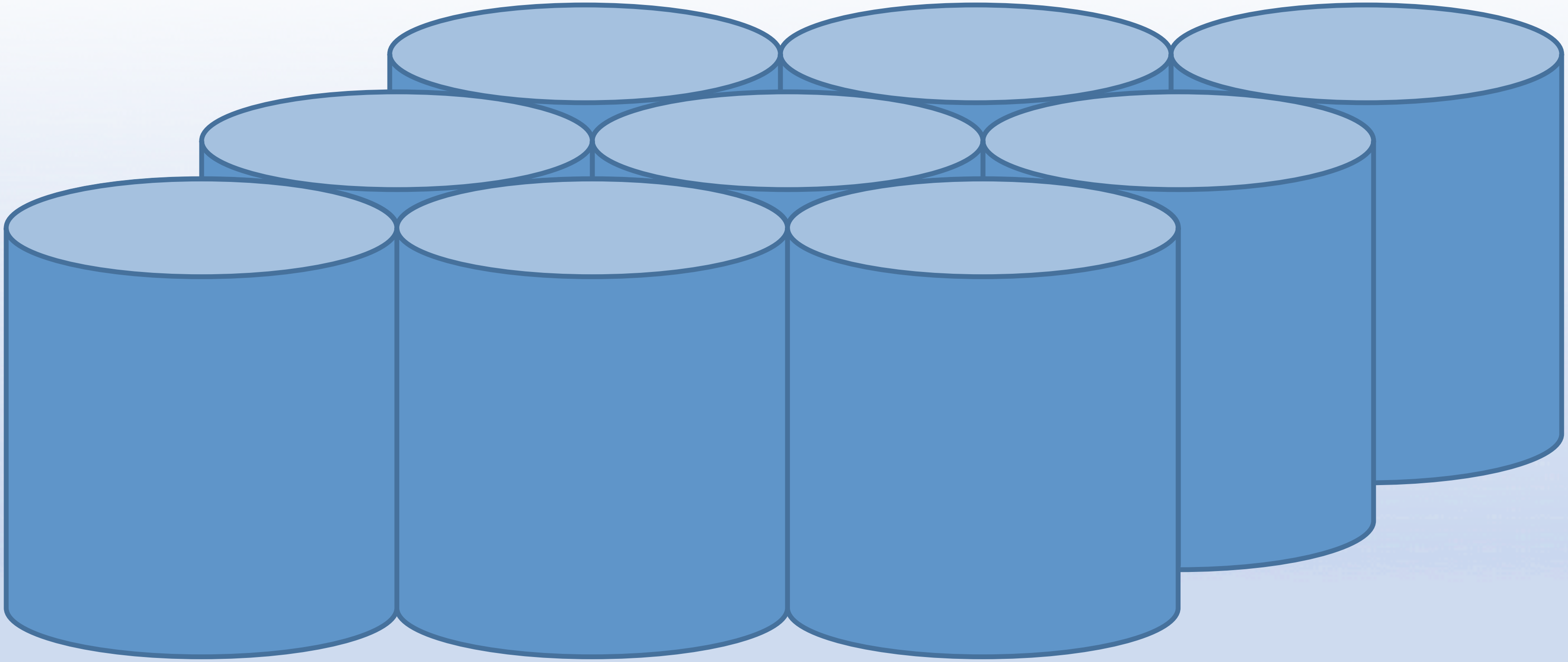
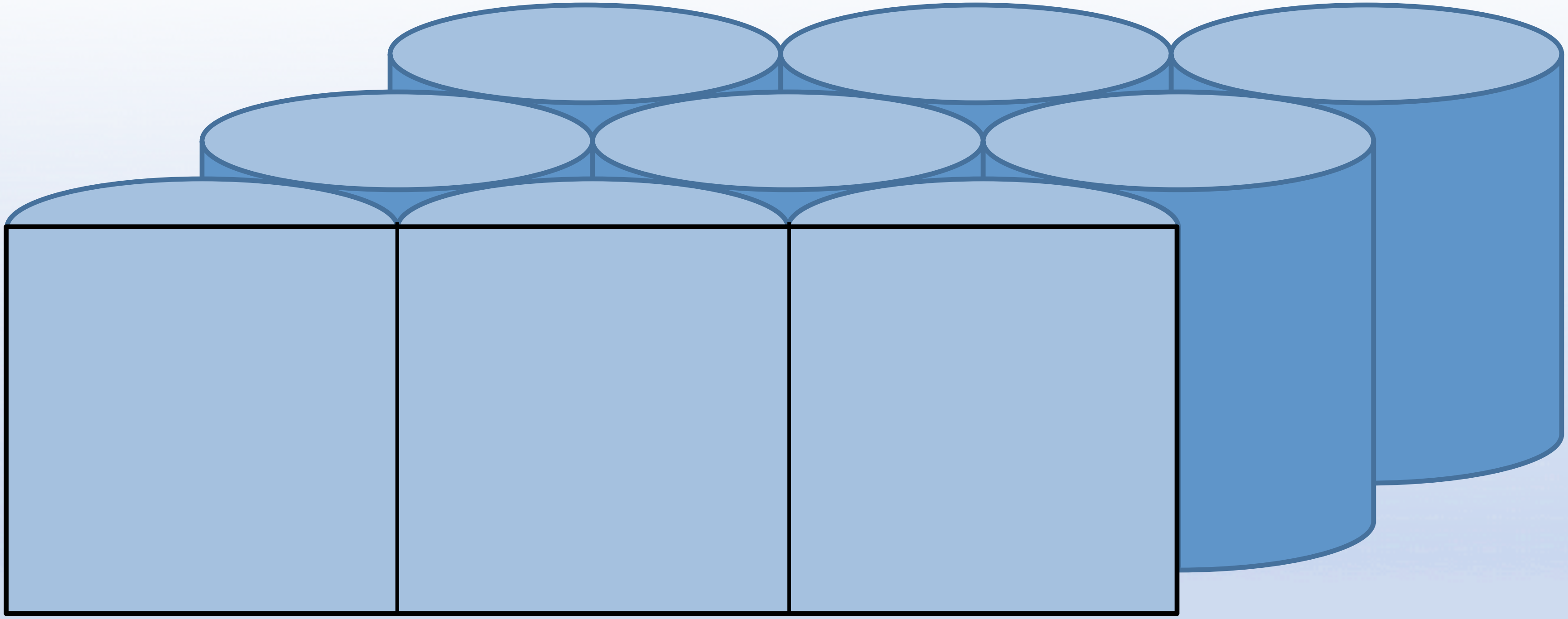
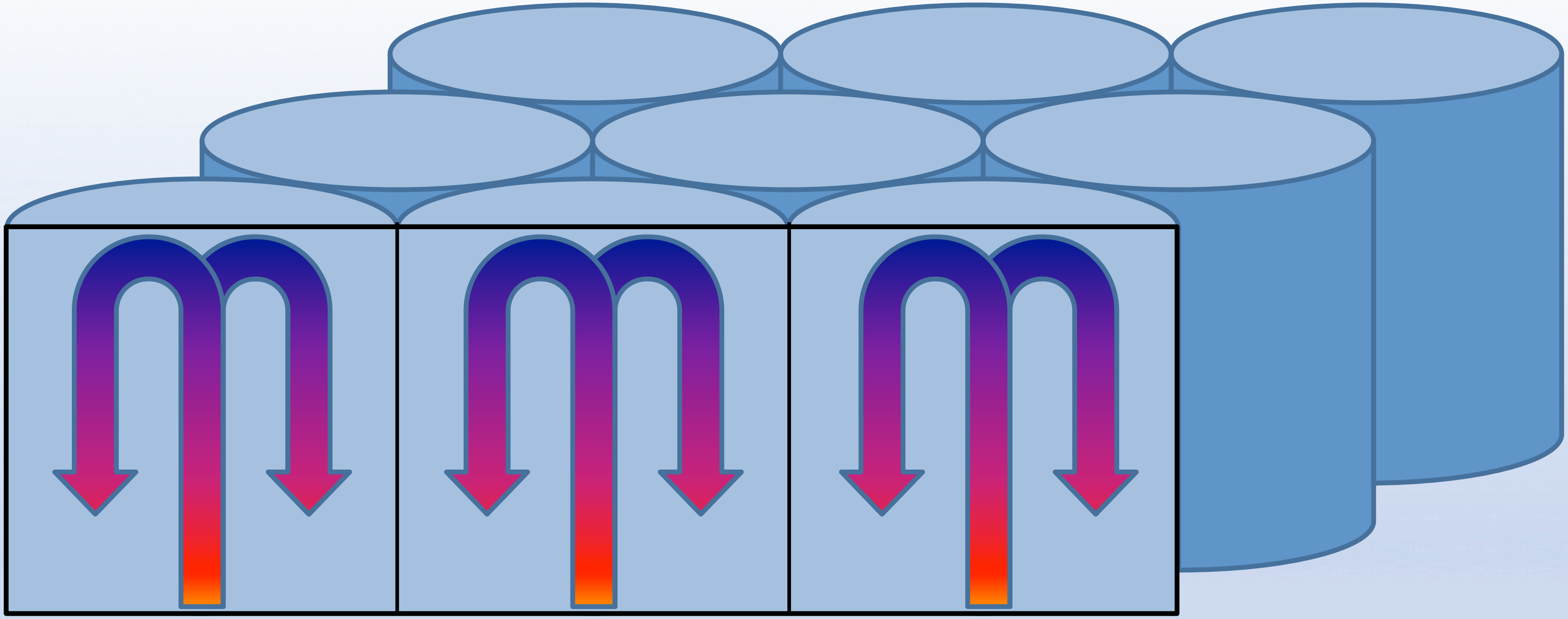


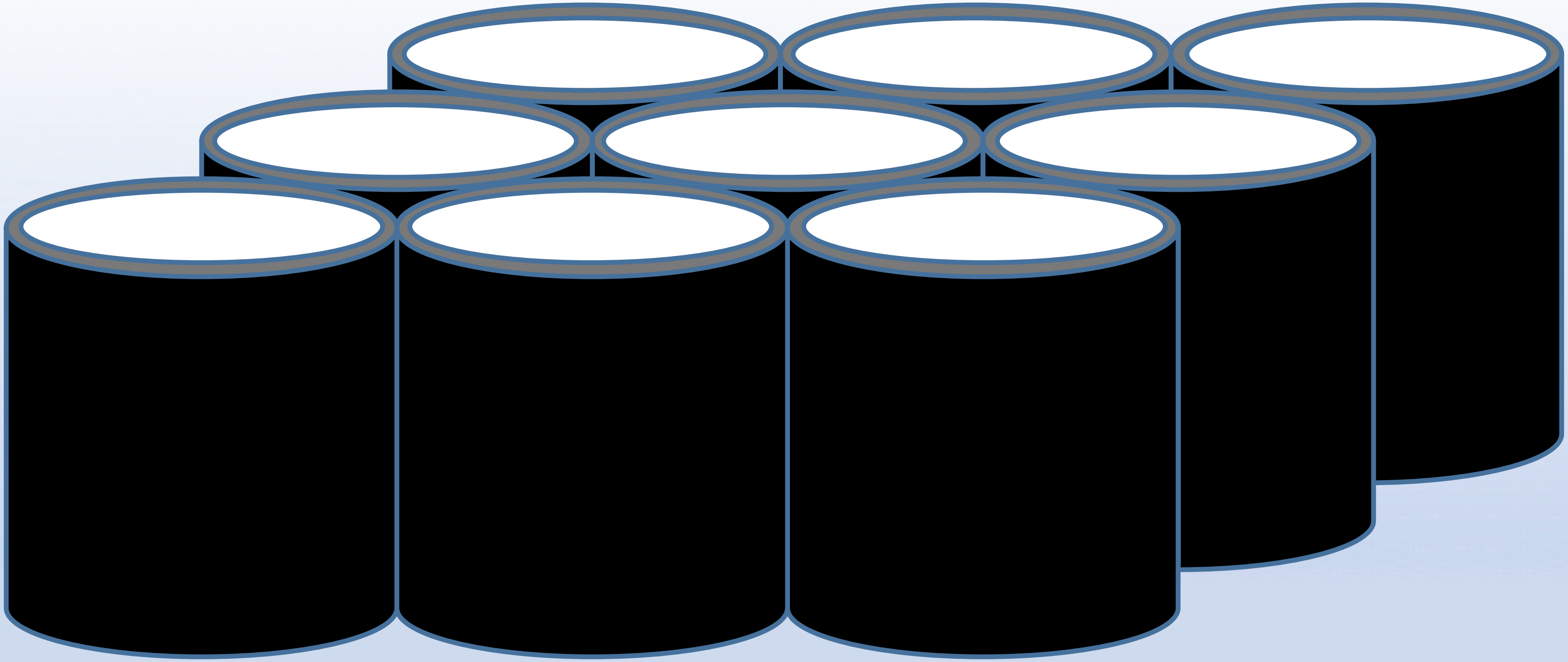
Questions related to Thermodynamic and microphysical process

Complexity

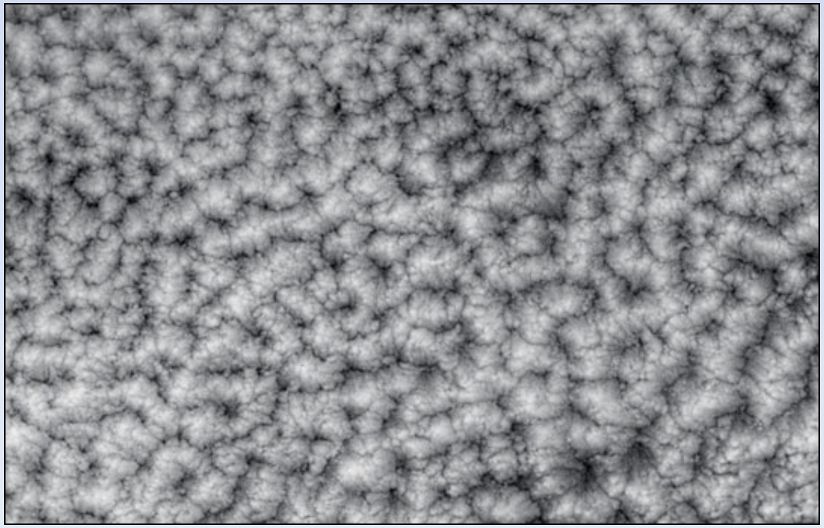


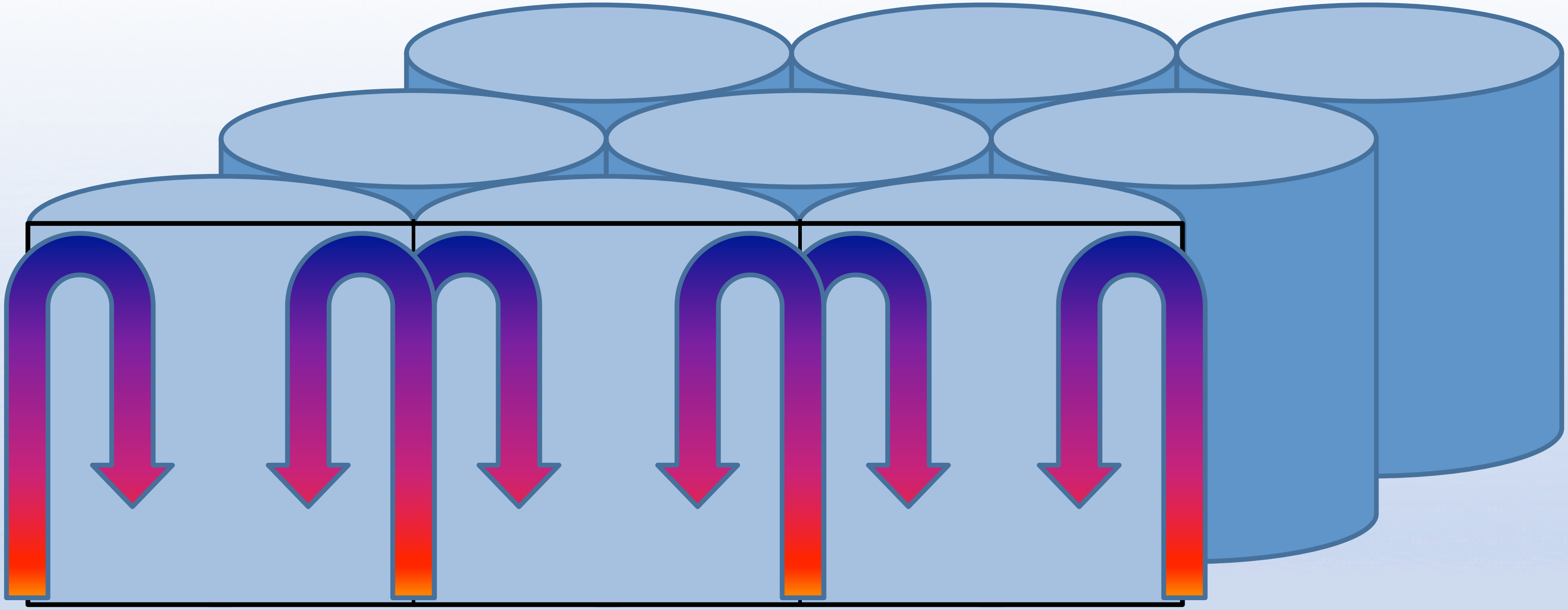


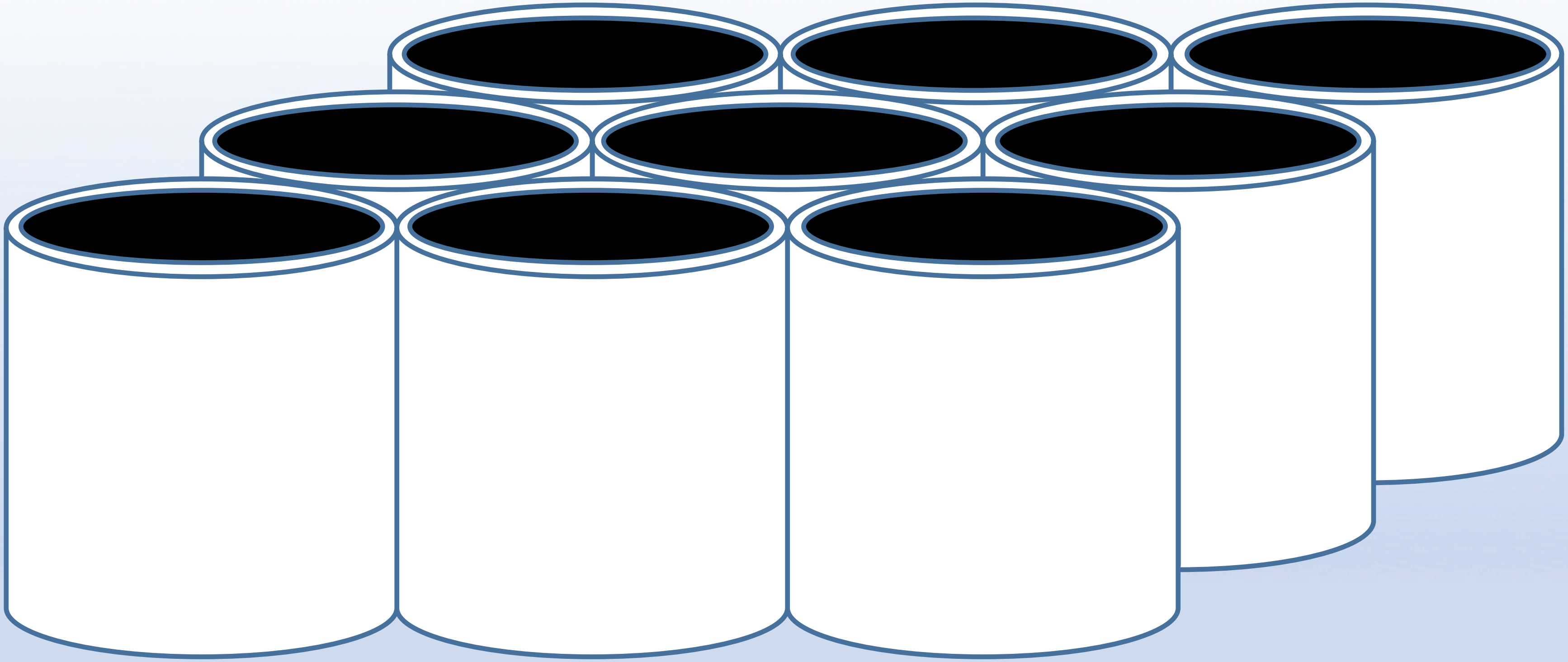




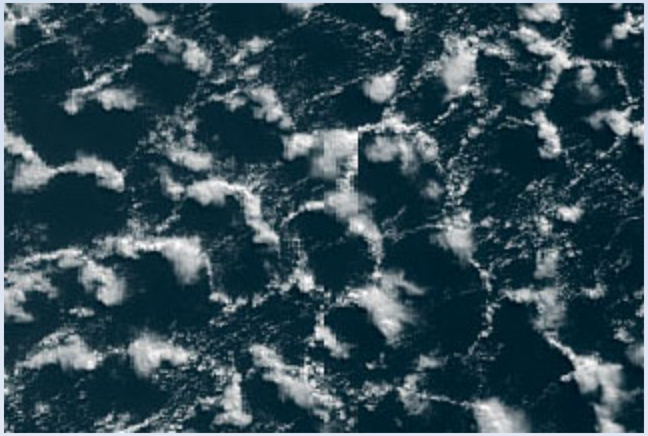
Closed cell formation







Open cell formation



Systems Approach to cloud-drizzle-aerosol problem

Looking for the **Emergent Behavior**

Basic rules:

Basic rules:

1)Cloud evolution

Basic rules:

1) Cloud evolution
2) Rain Consume clouds

Basic rules:

1) Cloud evolution
2) Rain Consume clouds
3) Delay

Basic rules:

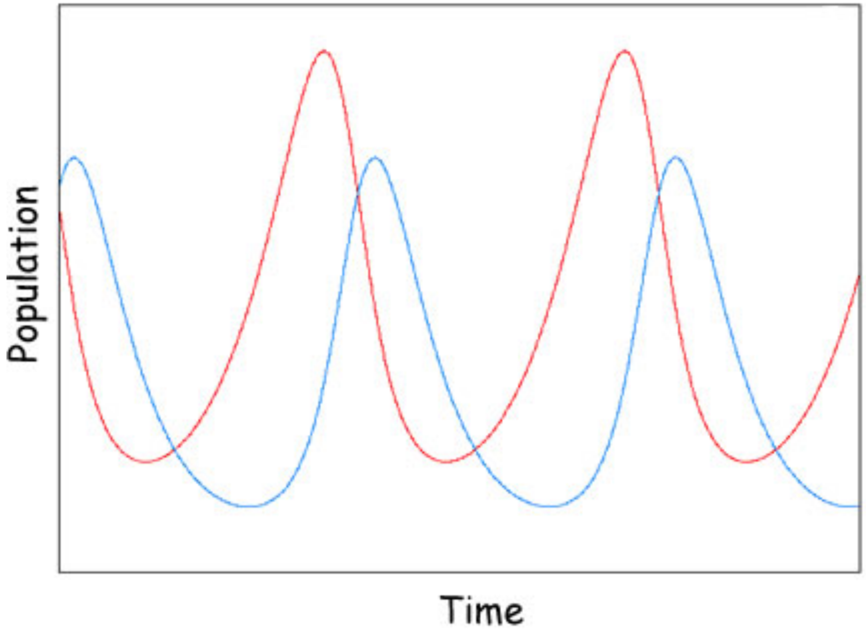
1) Cloud evolution
2) Rain Consume clouds
3) Delay
4) Aerosol effects on the above

Predator-Prey Model

Lotka-Volterra Equation for Population Dynamics
(circa 1925)

$$\frac{dx}{dt} = x(\alpha - \beta y)$$

$$\frac{dy}{dt} = -y(\gamma - \delta x)$$



$x =$ prey

$y =$ predator

$$\mathrm{LWP} = \int_0^H q(z)dz = \frac{c_1}{2}H^2,$$

$$\dot{H}_r = \frac{dH}{dt} = \frac{dH}{d\mathrm{LWP}}\frac{d\mathrm{LWP}}{dt},$$

$$\frac{dH}{dt} = \frac{H_0 - H}{\tau_1} - \dot{H}_r(t-T).$$

$$\dot{H}_r = \frac{1}{c_1 H}R = \frac{\alpha H^2}{c_1 N_d},$$

$$R = \alpha H^3 N_d^{-1}$$

$$\frac{dN_d}{dt} = \frac{N_0 - N_d}{\tau_2} - \dot{N}_d(t-T).$$

$$R \propto \frac{d\mathrm{LWP}}{dt},$$

$$R(t) = \frac{\alpha H^3(t-T')}{N_d(t-T')}$$

$$\frac{dH}{dt} = \frac{H_0 - H}{\tau_1} - H_r(t - T)$$

Cloud Depth H:

Source term due to meteorology
Sink term due to rain (with delay)

$$\frac{dN_d}{dt} = \frac{N_0 - N_d}{\tau_2} - \frac{\delta N_d}{dt}(t - T)\bigg|_{sink}$$

Drop concentration N_d:

Source term due to aerosol sources
Sink term due to coalescence (with delay)

$$R(t) = \frac{\alpha H^3(t - T')}{N_d(t - T')}$$

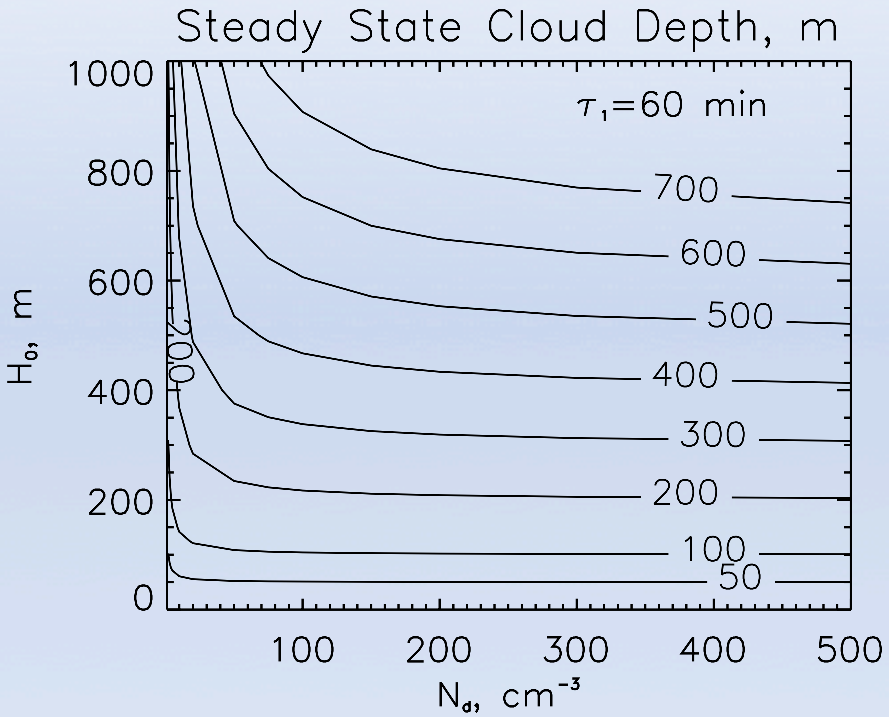
Rainrate R

Based on Theory (Kostinski 2008) and many Observations

Koren and Feingold (2011)

Steady State Solution to Cloud Depth H

$$\frac{dH}{dt} = \frac{H_0 - H}{\tau_1} - H_r(t - T) = 0$$



Koren and Feingold (2011)

Steady State Solution to Cloud Depth H

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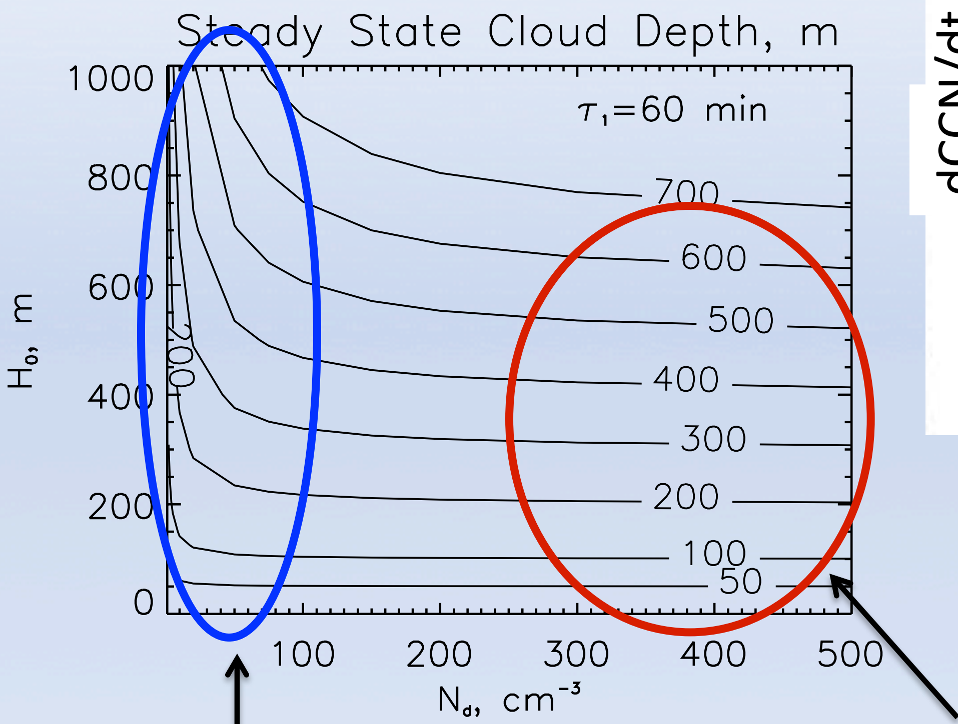
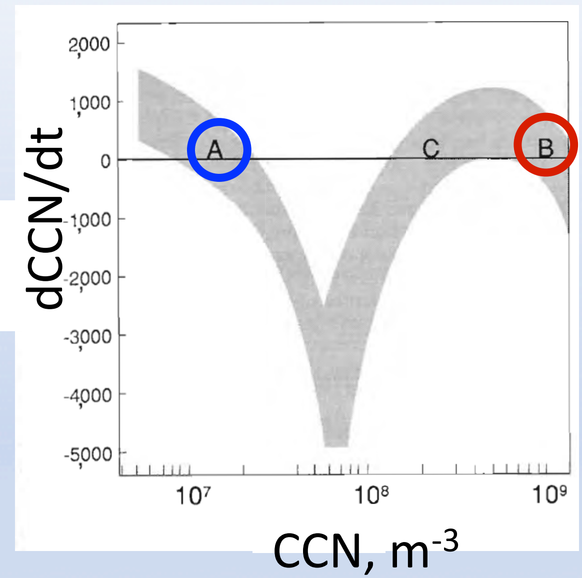




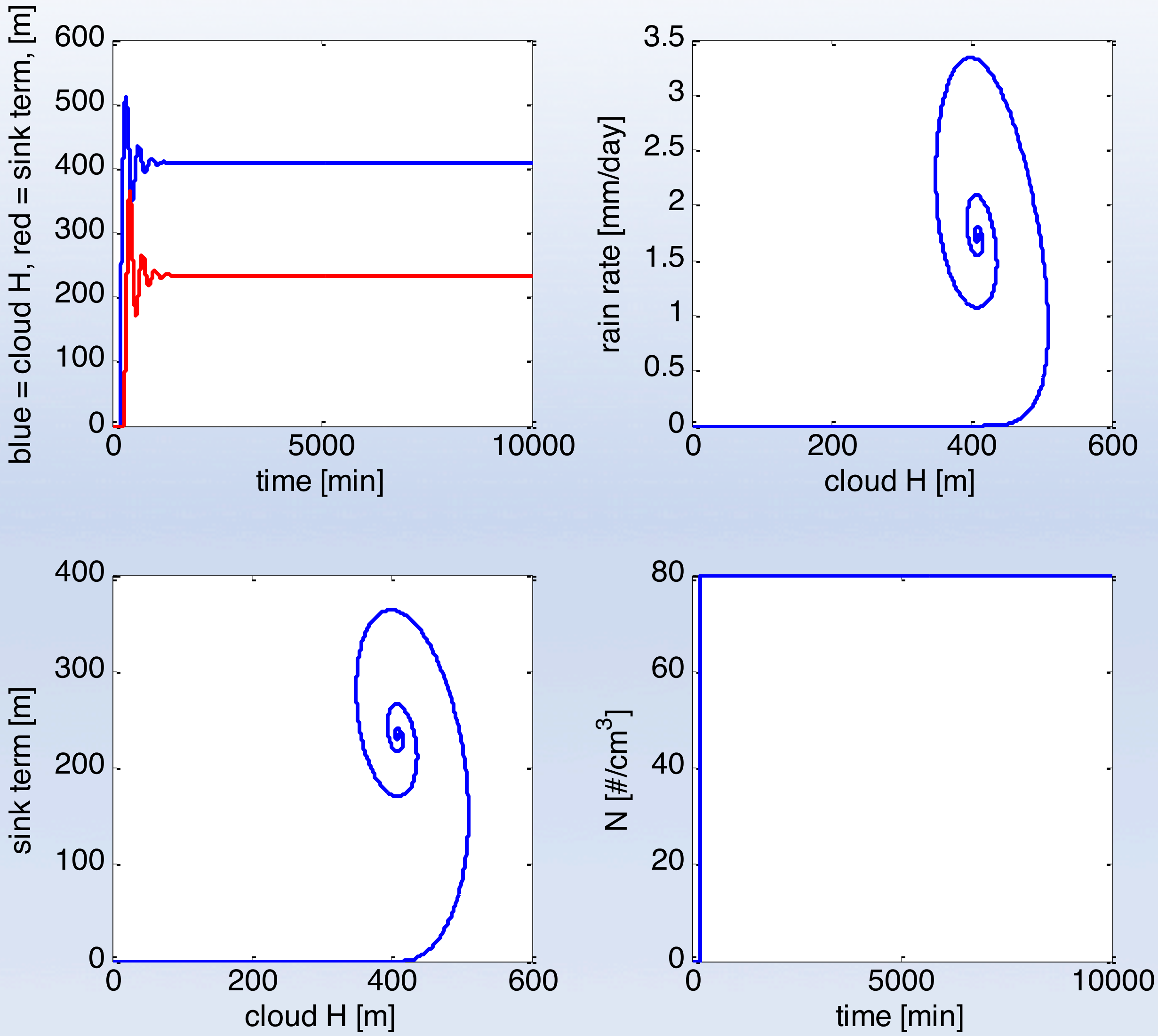
Baker and Charlson, 1990

Cloud Depth determined by H_0

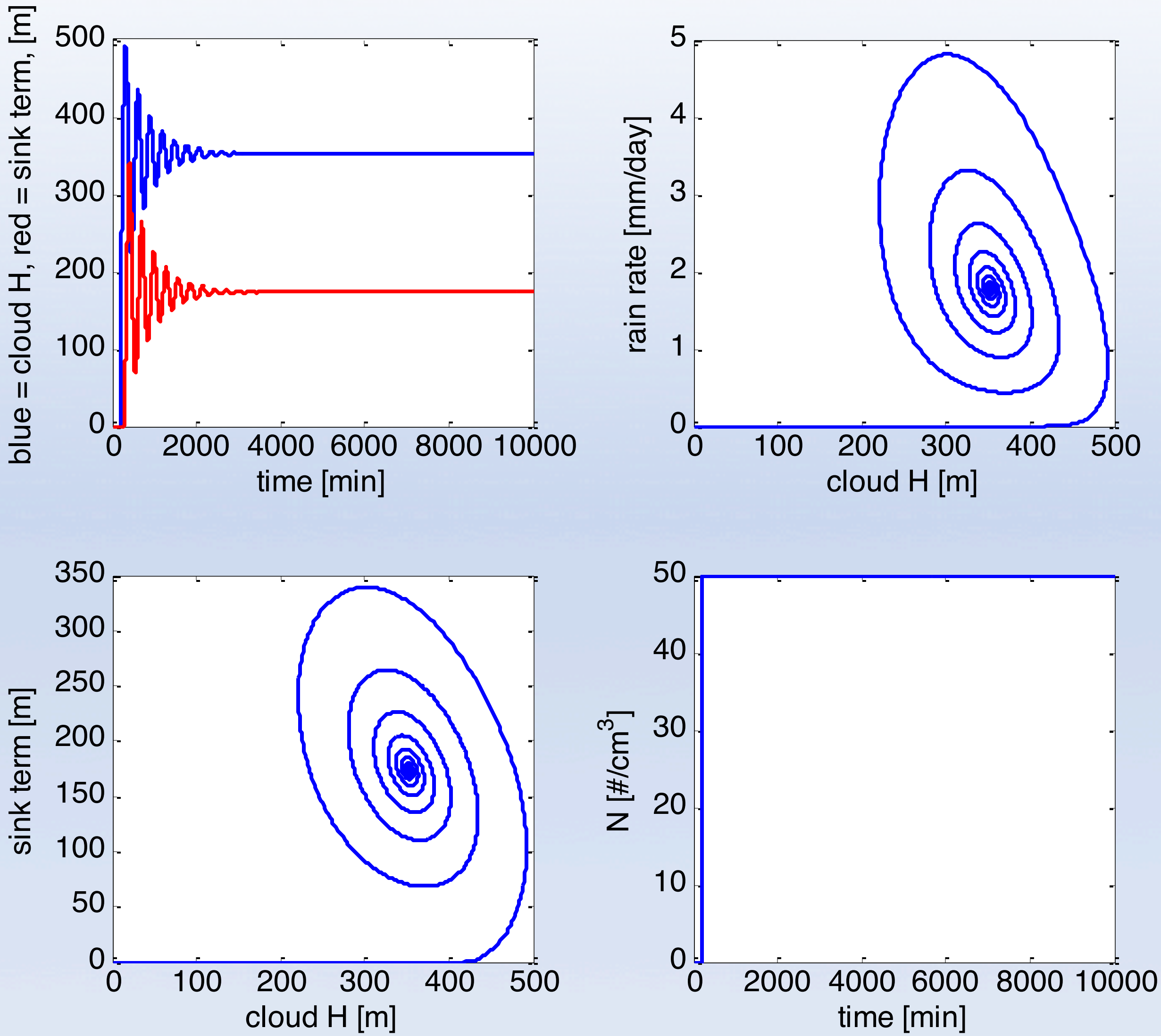
Cloud Depth determined by drop concentration N_d

Koren and Feingold (2011)

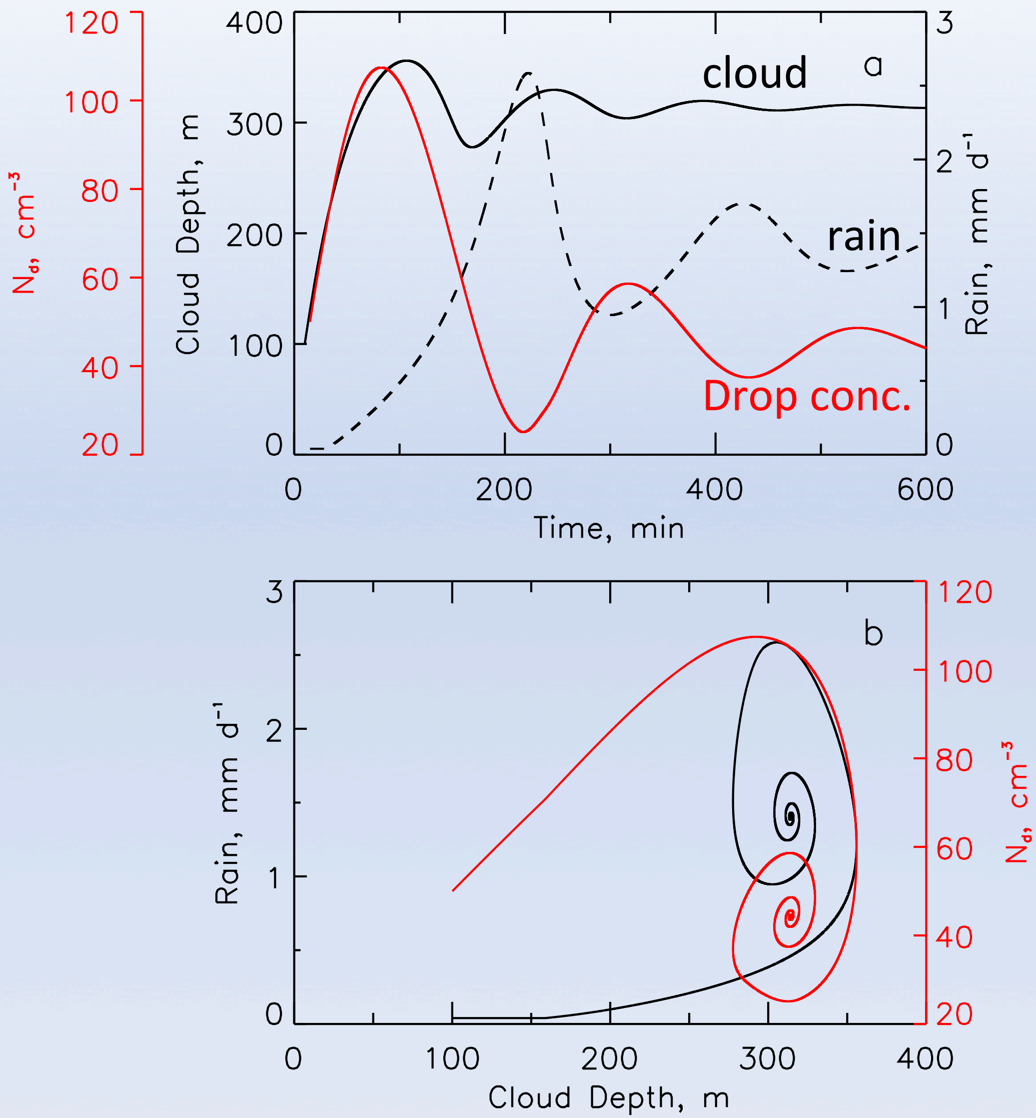
H0 = 700, τ of the cloud = 100 mins
delay = 90 mins, N=80



H0 = 700, τ of the cloud = 100 mins
delay = 90 mins, N=50



Stable States



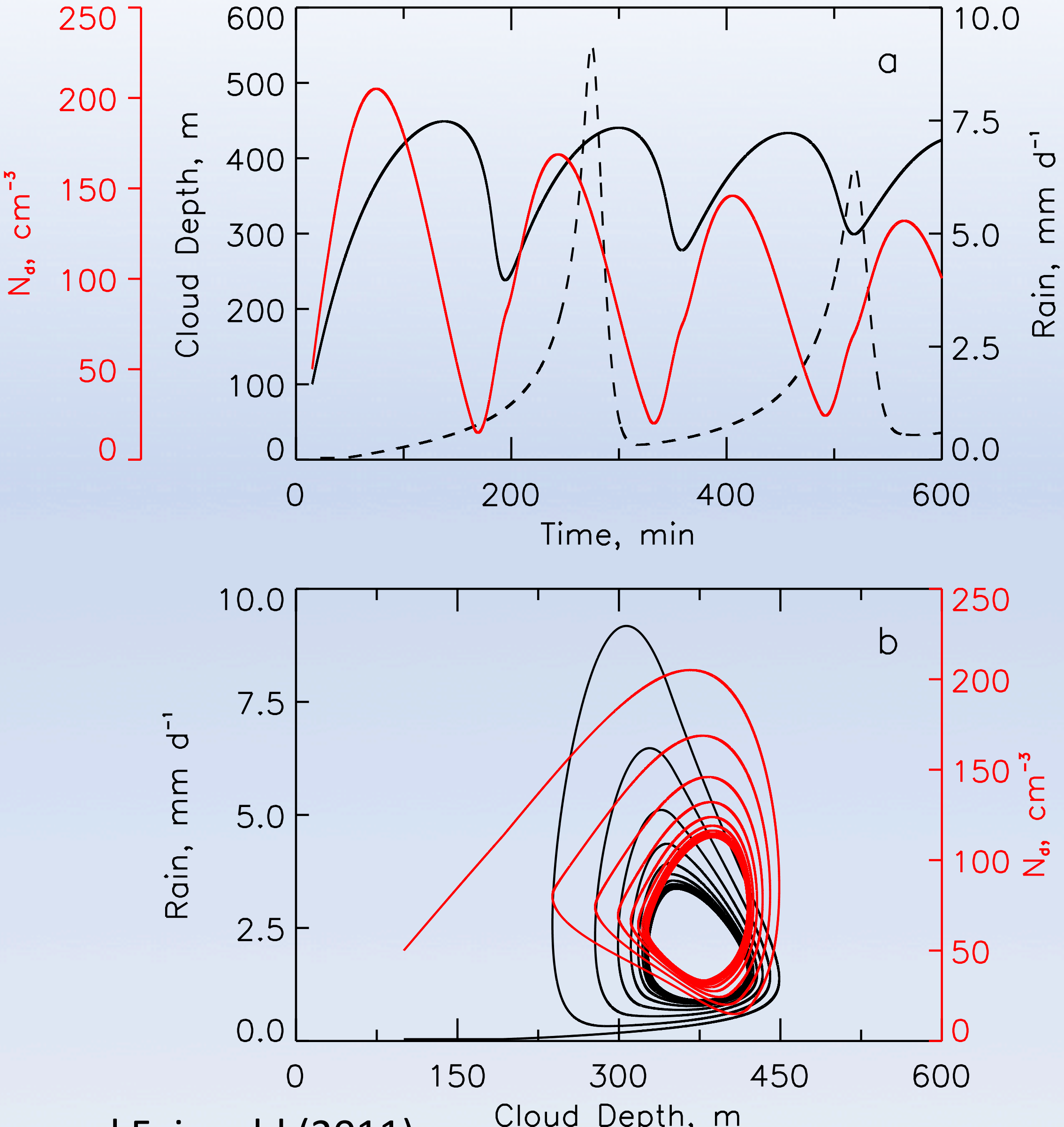
At steady state:
Aerosol sources are sufficient to maintain balance between sources and rainfall removal

Cloud depth-N
Cloud depth-R

~ 7 day simulation

Koren and Feingold (2011)

Stable States: Oscillation around a mean state



Stronger rain: Oscillations around a steady state

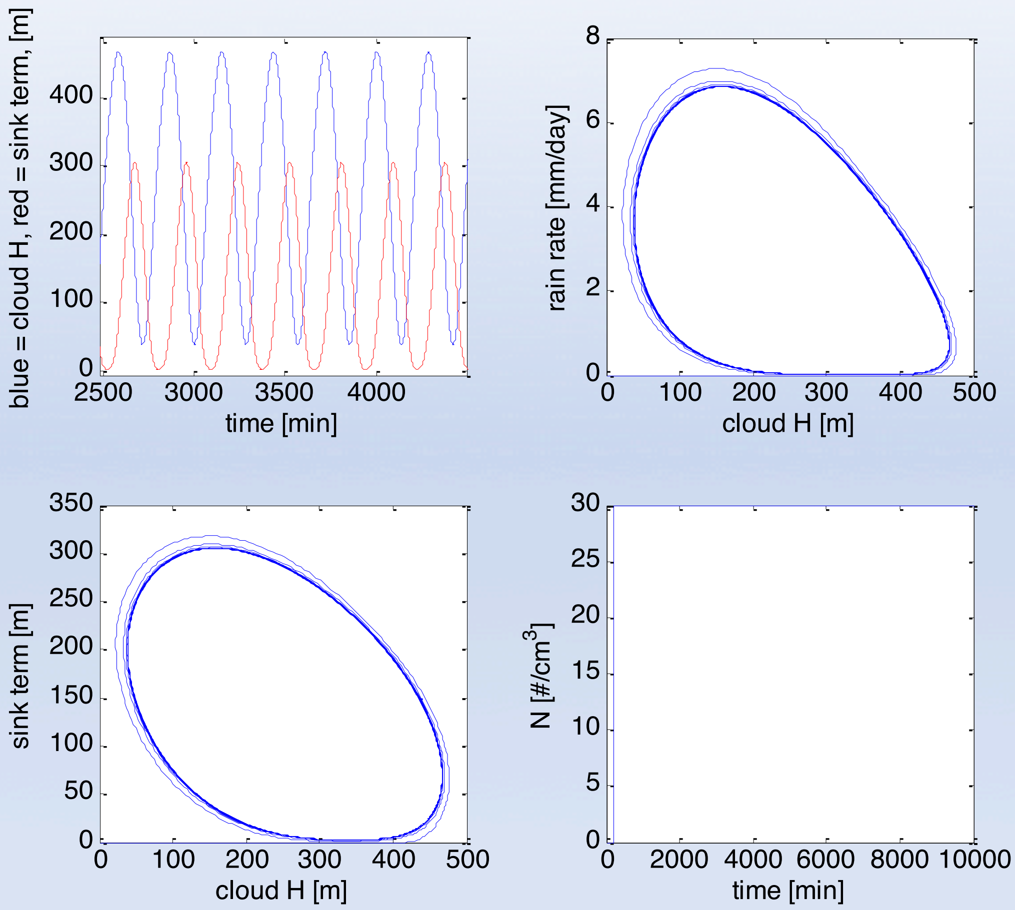
Cloud depth-N

Cloud depth-R

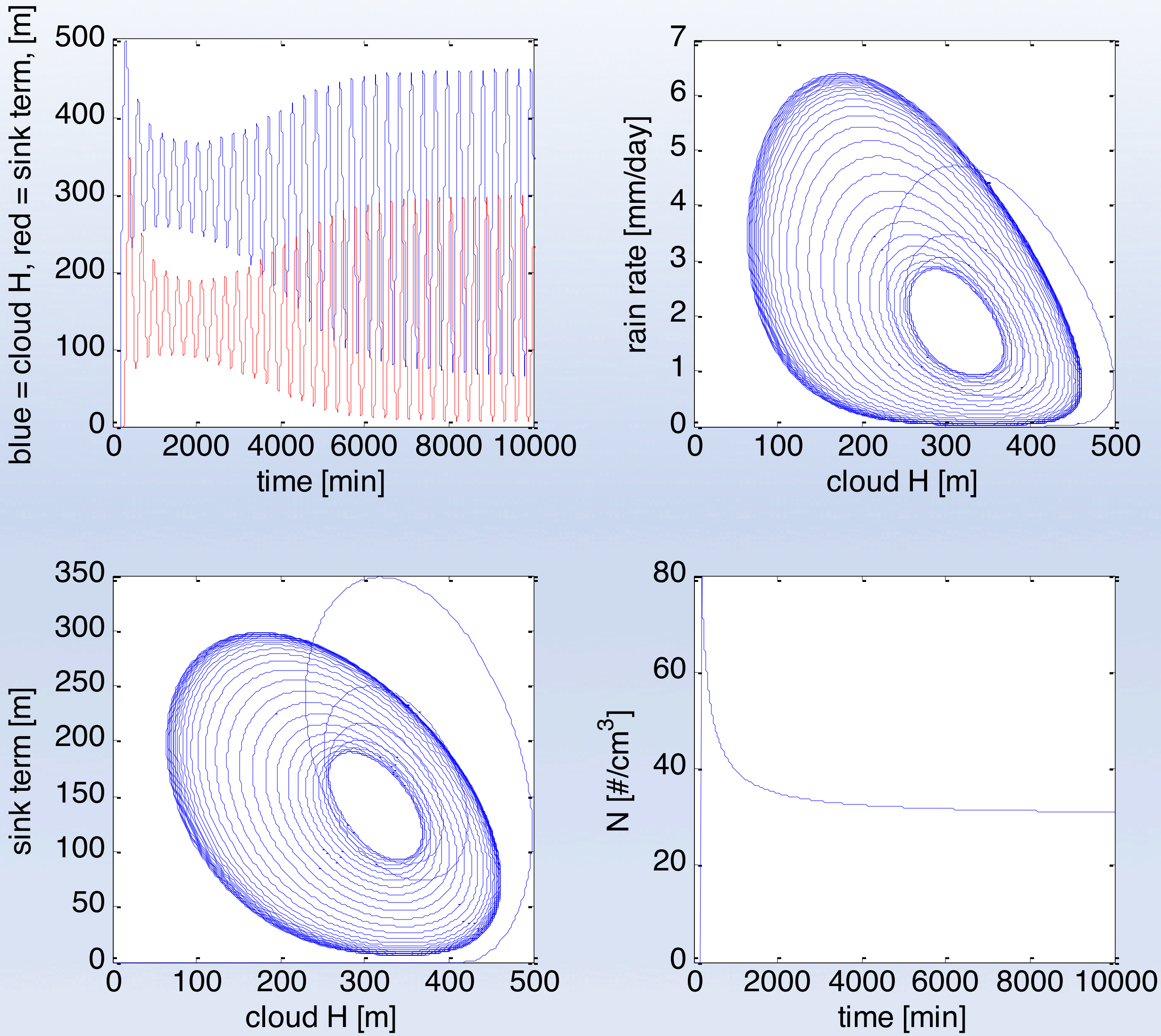
~ 7 day simulation

Koren and Feingold (2011)

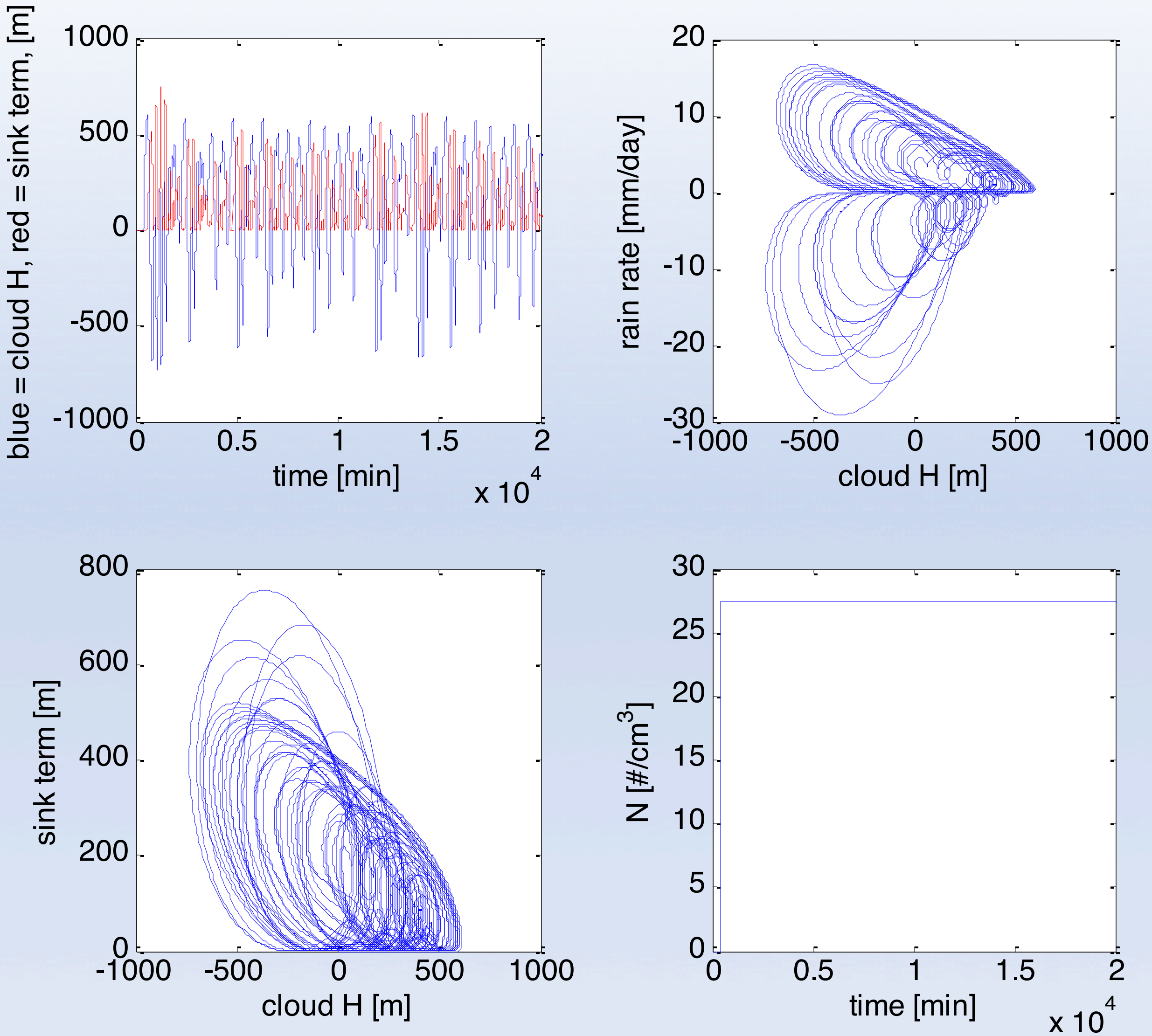
H0 = 700, τ of the cloud = 100 mins
delay = 90 mins, N=30



H0 = 700, τ of the cloud = 100 mins
delay = 90 mins, N=80 to 30

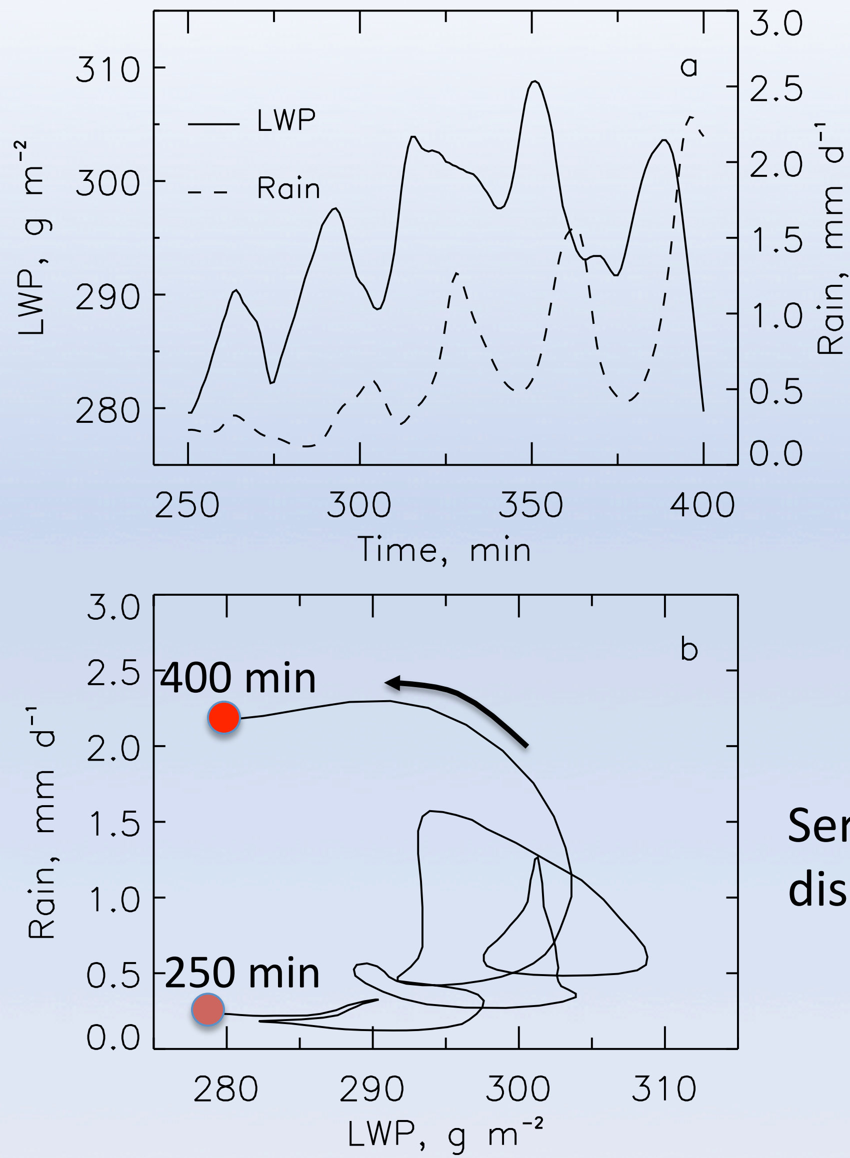


H0 = 700, τ of the cloud = 100 mins
delay = 190 mins, N=27



Oscillations?

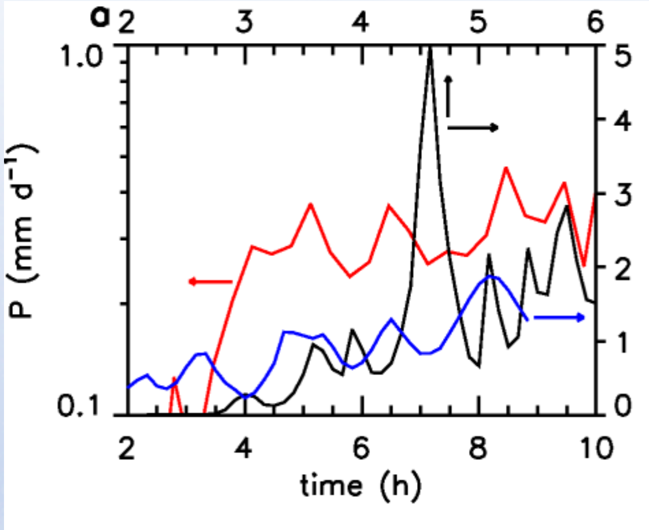
Large Eddy Simulation: Predator-Prey Characteristics



Series of anticlockwise displaced loops

Adapted from Feingold and Kreidenweis 2002

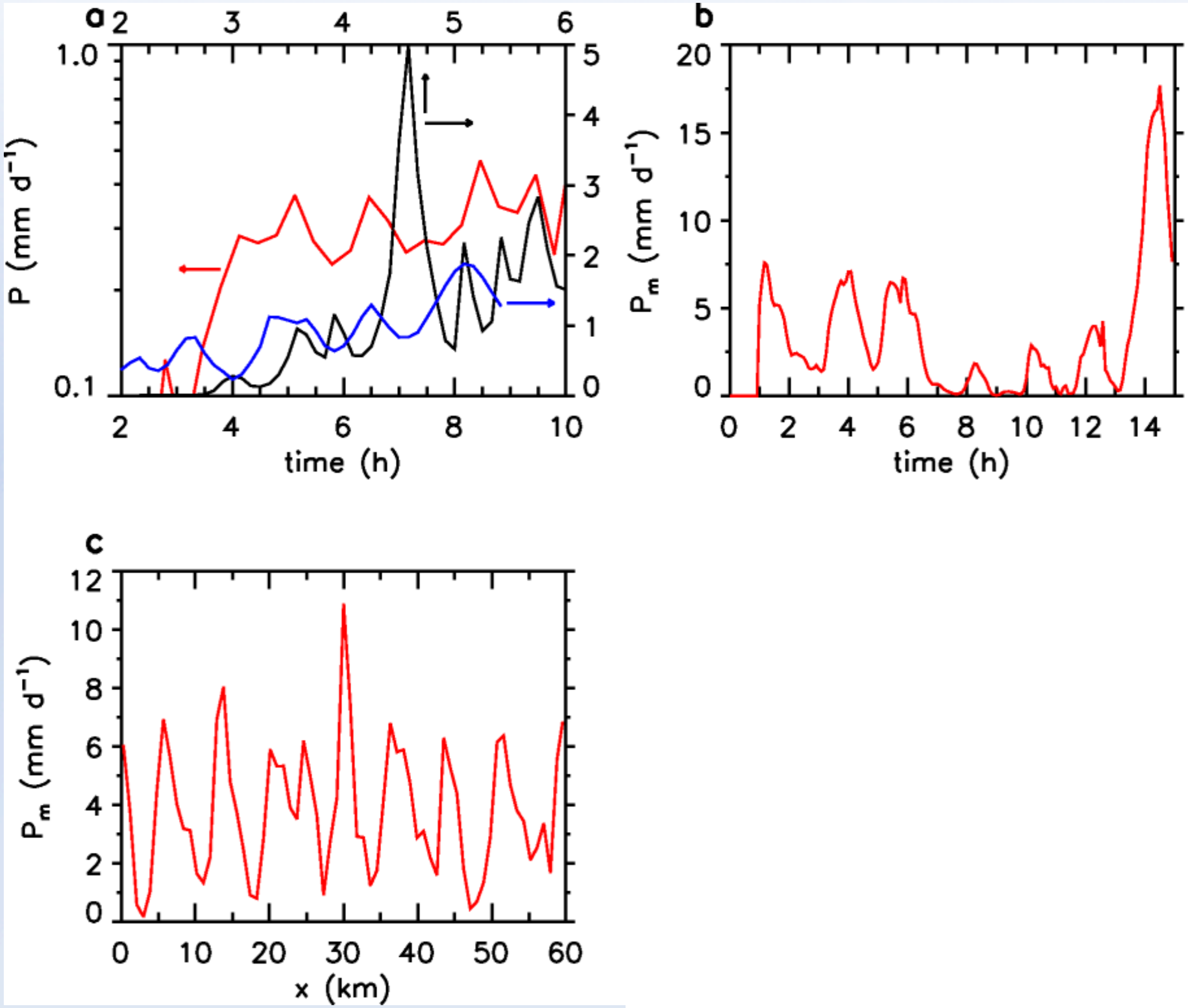
Synchronization: Oscillations in Precipitation



3 cases:
DYCOMS
ATEX
VOCALS

Feingold, Koren, Wang, Xue, Brewer (2010)

Synchronization: Oscillations in Precipitation



3 cases:
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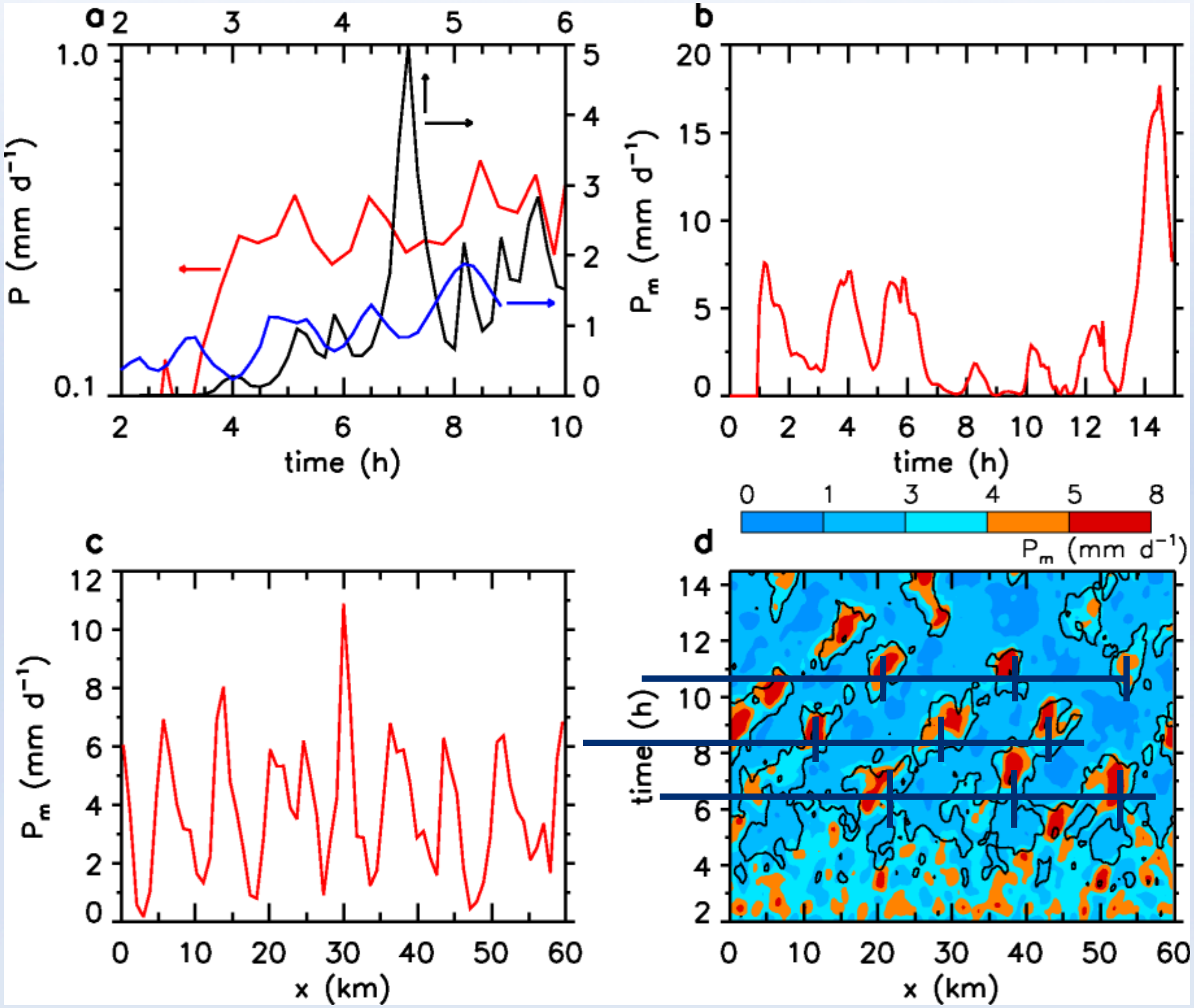
Synchronization: Oscillations in Precipitation



3 cases:
DYCOMS
ATEX
VOCALS

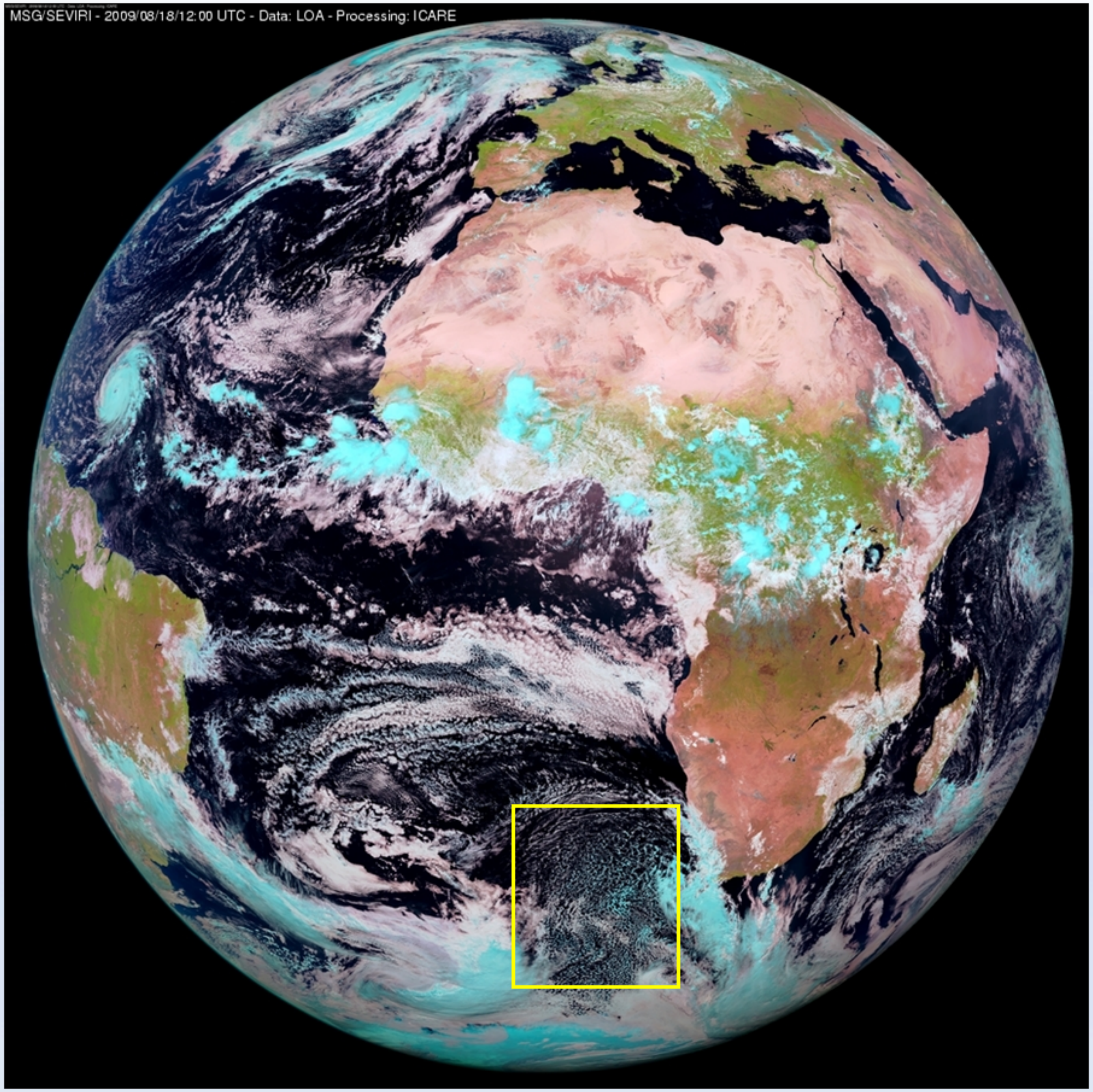
Hovmöller diagram

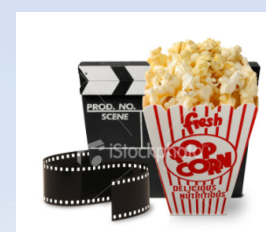
Shift in rain "grid"

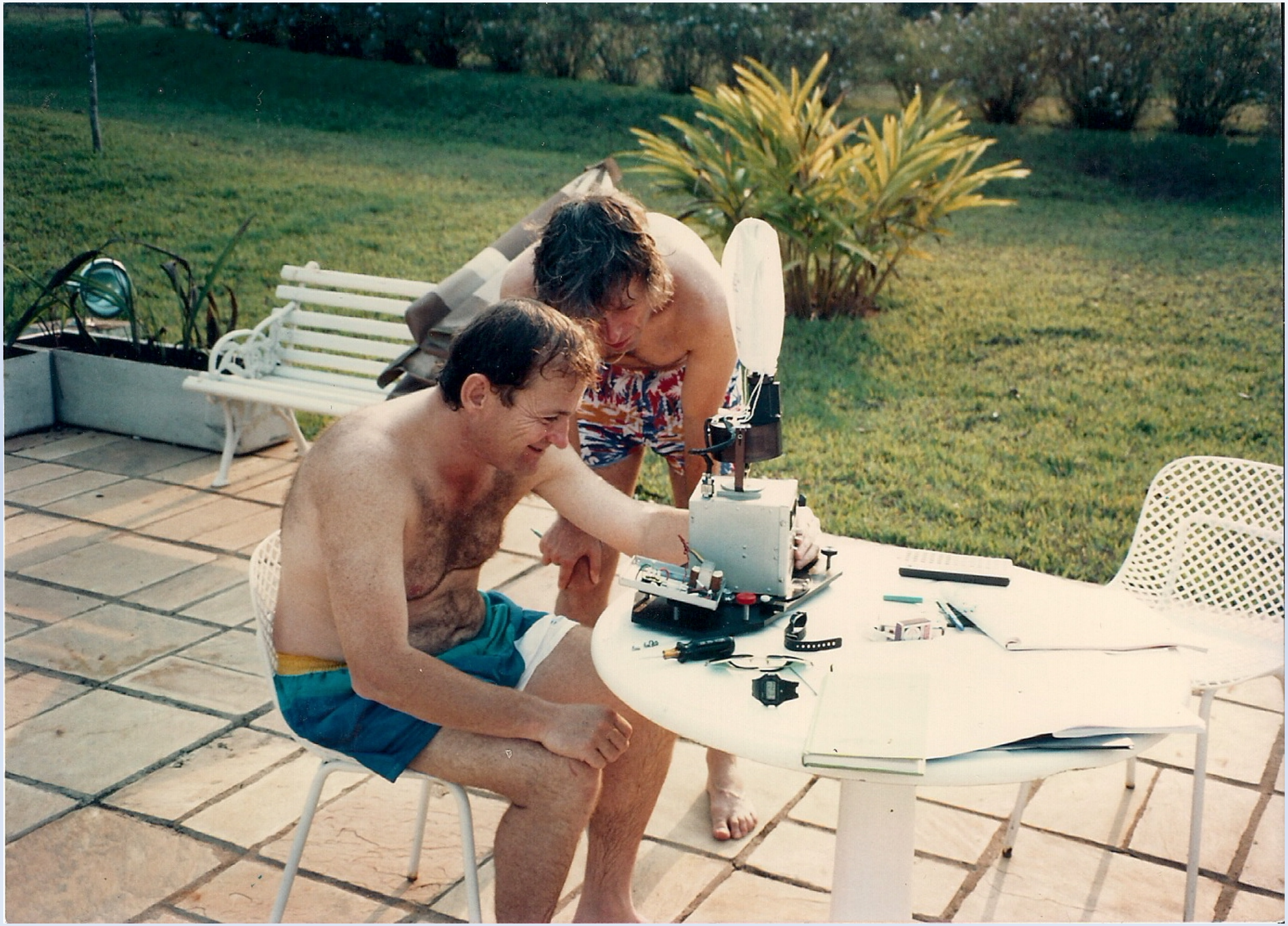
Colored contours: rain

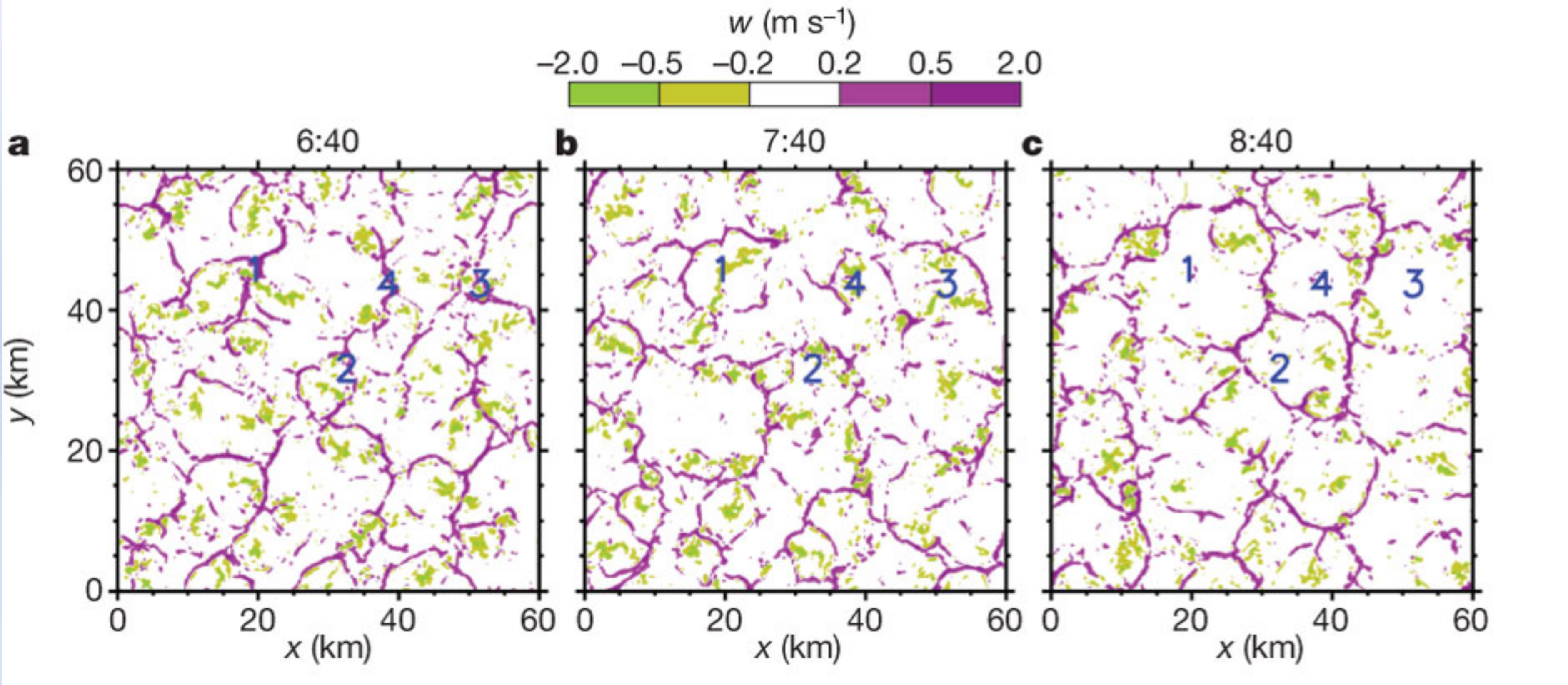
Contours: updraft

Feingold, Koren, Wang, Xue, Brewer (2010)

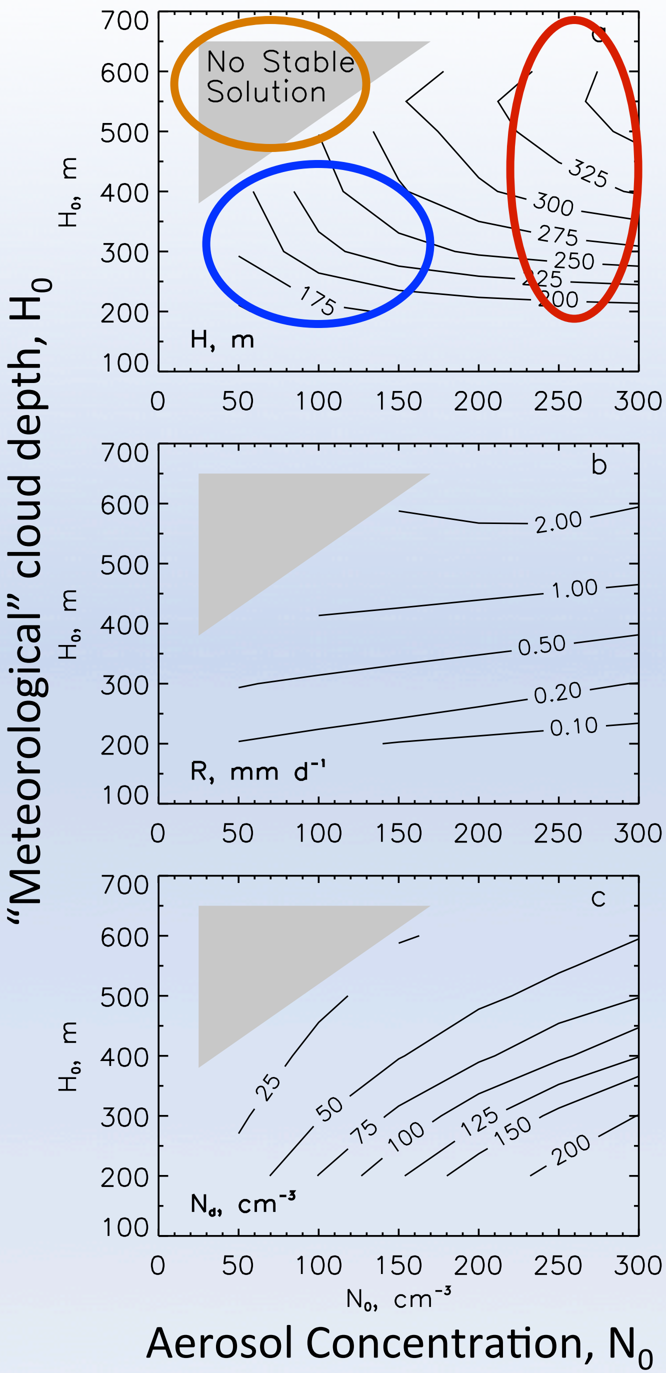

MSG/SEVIRI - 2009/08/18/12:00 UTC - Data: LOA - Processing: ICARE


PROD. NO.
SCENE
fresh
POP CORN





w (m s⁻¹)
−2.0
−0.5
−0.2
0.2
0.5
2.0
a
6:40
b
7:40
c
8:40
60
40
20
0
y (km)
0
20
40
60
x (km)
1
2
3
4



Time-Dependent Steady State Solutions

$$\frac{dH}{dt} = \frac{H_0 - H}{\tau_1} - H_r(t - T)$$

$$R(t) = \frac{\alpha H^3(t - T')}{N_d(t - T')}$$

$$\frac{dN_d}{dt} = \frac{N_0 - N_d}{\tau_2} - \frac{\delta N_d}{dt}(t - T)\bigg|_{sink}$$